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BALLISTIC NOMOGRAPHS

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DEPARTMENT OF THE NAVY
NAVAL AIR DEVELOPMENT CENTER
WARMINSTER, PA. 18974

AIR VEHICLE TECHNOLOGY DEPARTMENT

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FINAL REPORT

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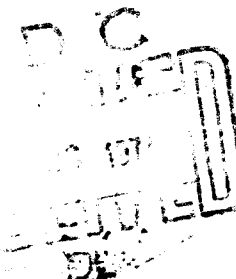
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INTRODUCTION

Time of fall and wind dispersion are two important parameters of air launched stores. Particularly in the application of aerodynamic decelerators to sonobuoys, the time of fall is a determining factor in the lag time from sensor launch to reception of buoy outputs and wind dispersion is a major factor in determining placement accuracy of the buoy. This report presents nomographs which predict the time of fall and wind drift of air launched stores with single stage decelerators.

The report fulfills many objectives. The use of the nomographs is explained and examples of their use are included. The section titled "Aerodynamic Background" details the source of the information presented on the nomographs and the assumptions made. Topics in that section include the relations between the variables, the time of fall approximation, an explanation of the FORTRAN program DRIFT which produced the data used in the nomographs, and selection of a wind profile. Construction of the nomographs is also reviewed as is the accuracy of the information obtained from them.

Typical use of the nomographs for analysis requires knowledge of the launch altitude and either the ballistic coefficient or terminal velocity of the store. Knowing these, time of fall and wind drift may be read directly. The nomographs may also be used in design problems to specify the required ballistic coefficient and terminal velocity to satisfy a given launch altitude and corresponding time of fall or wind drift. They will also specify the launch altitude meeting constraints on the other parameters. Limitations of the nomographs are summarized in the conclusions.

USE OF NOMOGRAPHS

Figure 1 is a nomograph which indicates time of fall from altitudes to 40,000 feet given terminal velocity or ballistic coefficient, β , (quotient of store's weight divided by its effective drag area) of an air deployed store. Figures 2 and 3 are nomographs which give the drift of a store when subjected to cross winds of the magnitude shown in figure 4. Note that figure 2 is useful for launch altitudes to 30,000 feet and figure 3 is for 30,000 to 40,000 feet.

The procedure for using the three nomographs is the same. A straight line is constructed through the point on the altitude axis corresponding to the launch altitude and the point on the terminal velocity - ballistic coefficient axis corresponding to the given property of the store. The intersection of the constructed line and the third axis gives the time of fall (figure 1) or drift (figures 2 and 3). The dotted lines on the nomographs are an example of a system with a terminal velocity of 140 feet per second (ballistic coefficient of 23 pounds per square foot) launched from 30,000 feet. The indicated time

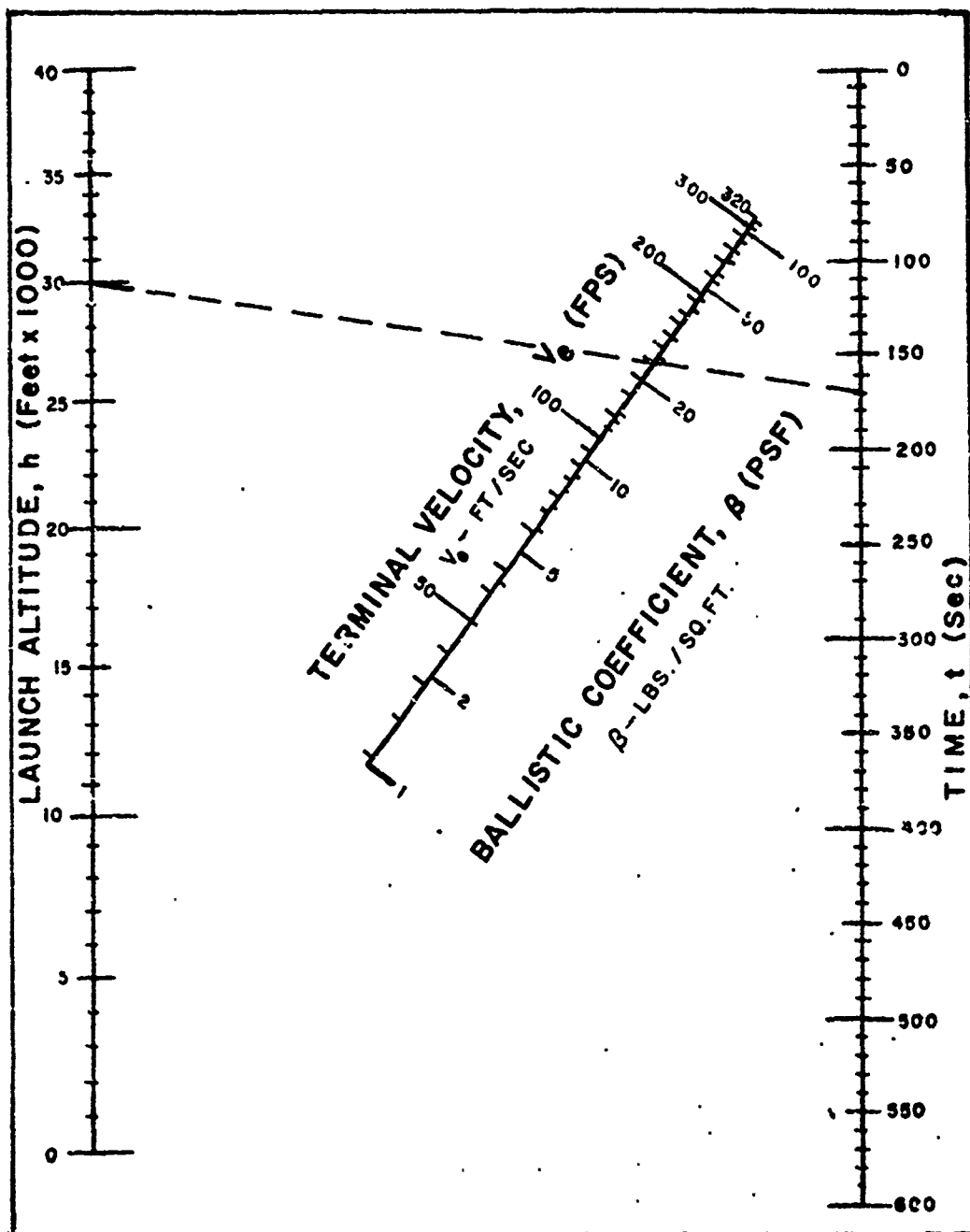


Figure 1. Time of Fall Nomograph

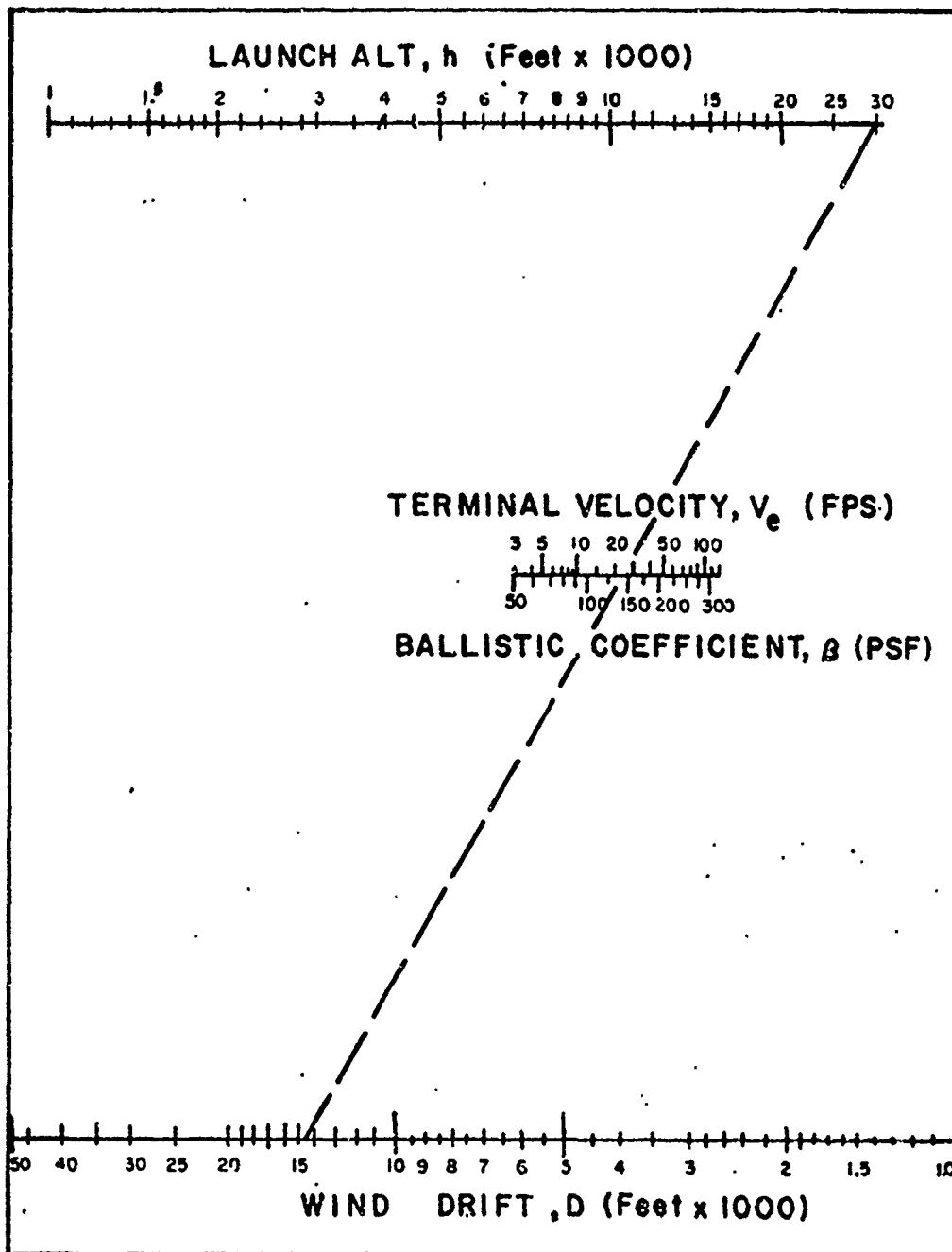


Figure 2. Wind Drift Nomograph
0 to 30,000-Ft. Launch

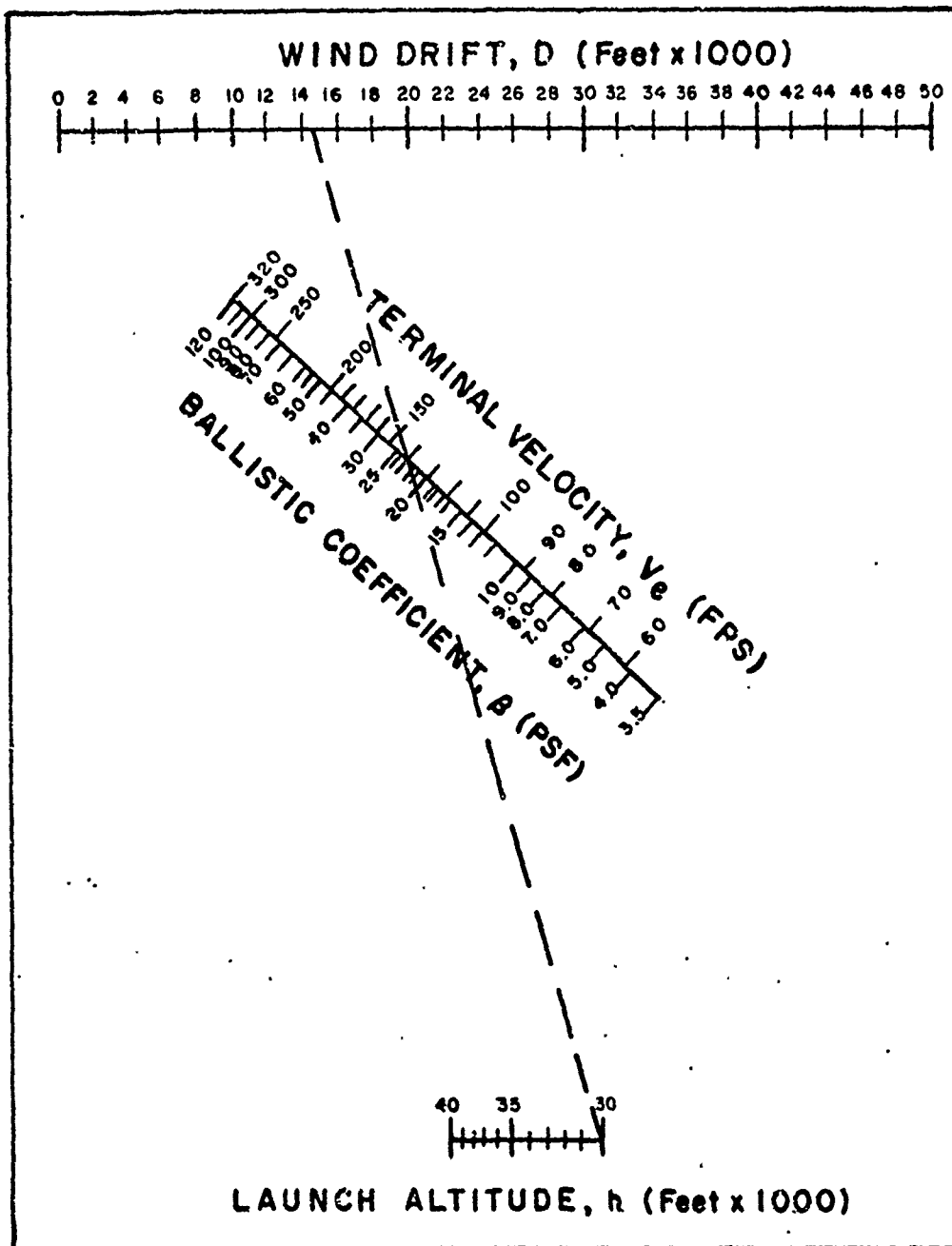


Figure 3. Wind Drift Nomograph
30 to 40,000 Ft. Launch

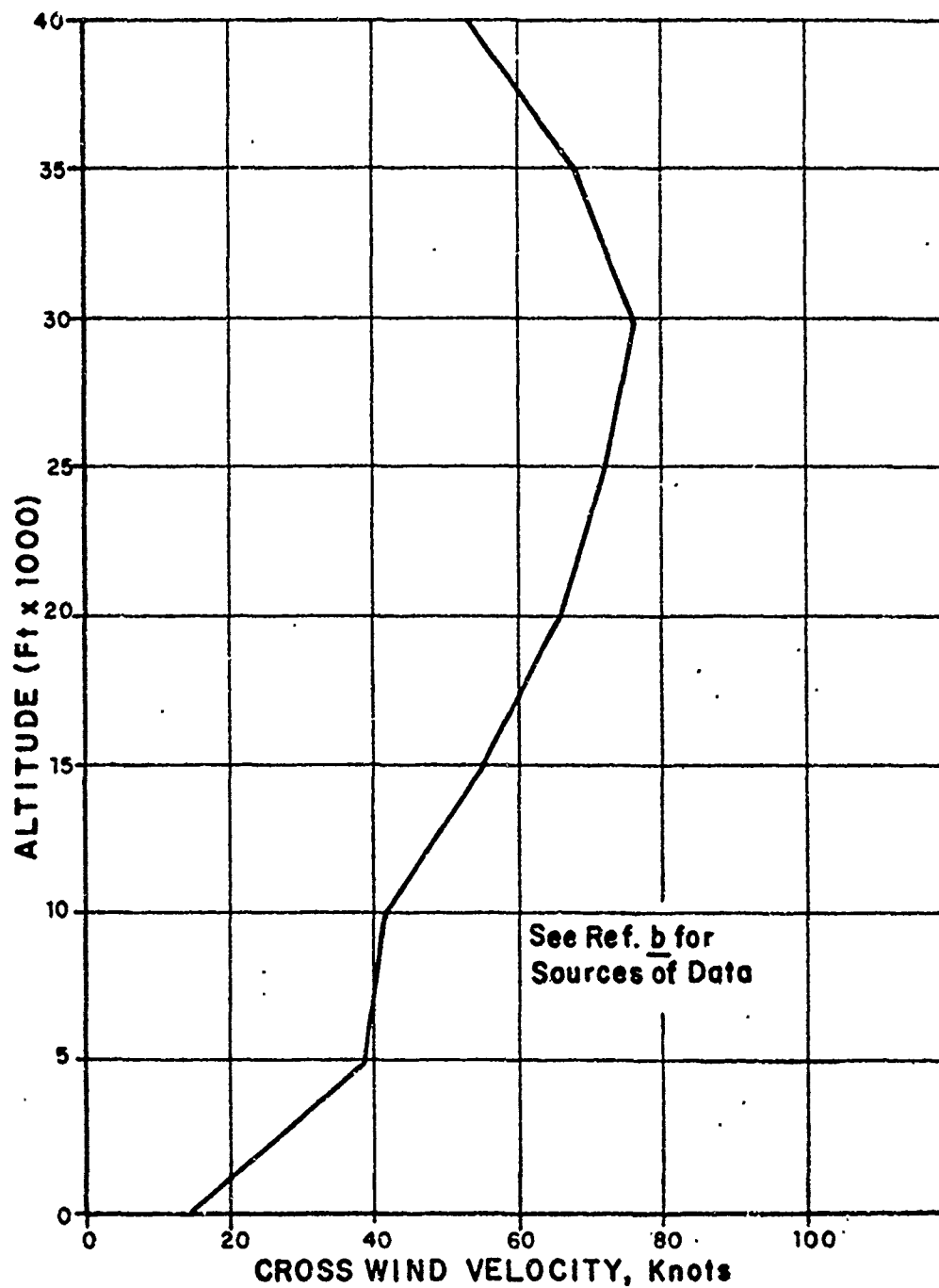


Figure 4. Wind Profiles

of fall is 170 seconds and the drift is indicated as 14,600 feet in both figures 2 and 3.

It is stressed that the indicated drift is that which corresponds to a cross wind of the profile shown in figure 4 and time of fall is given by the approximation discussed in the next section. Expected accuracy of the results is discussed in later sections of this report.

The nomographs may also be used as an adjacent conversion scale between terminal velocity and ballistic coefficient. Figure 1 is most convenient for this purpose because it has the longest terminal velocity - ballistic coefficient axis. To convert between the two parameters one merely selects the point on the axis corresponding to the known parameter and reads the value of that point on the unknown scale.

AERODYNAMIC BACKGROUND

Reference (a) derives a relation called the Standard Time of Fall relation which predicts descent time, t , as a function of ballistic coefficient¹, $\frac{W}{C_D S}$, and release altitude, h . Vertical descent at equilibrium velocity throughout the store trajectory is assumed in the derivation of this relation which is

$$t = a (1 - e^{-h/2a}) \left(2\rho_0 \frac{C_D S}{W} \right)^{\frac{1}{2}} \quad (*)$$

where a is an empirically determined constant equal to 31,600 feet below 40,000 feet and ρ_0 is the density at sea level, taken as .002378 slugs per cubic foot. The altitude of the target impact point being sea level is also implicit in the derivation of the relation (*). Larger ballistic coefficients, particularly from lower launch altitudes, violate the descent at equilibrium velocity assumption and therefore introduce errors in the time of fall nomograph. The extent of these errors will be discussed later.

The FORTRAN program DRIFT predicts flight trajectories of parachute retarded stores. The program is a three degree of freedom solution that considers the store a point mass subjected to a drag force in the direction of the relative wind vector. DRIFT was used to compute times of fall and wind drift for release altitudes from near sea level to 40,000 feet. Ballistic coefficients were varied between 3 and 120 pounds per square foot. The wind profile shown in figure 4 was treated as a cross wind, and as in reference (b) this profile has been selected to give comparative wind drift data for the various systems. The wind

¹ The term "canopy loading" is often used in the literature (including reference 1) as a synonym for "ballistic coefficient." Since the word canopy usually implies a textile decelerator, the more general term ballistic coefficient is used herein.

profile is somewhat arbitrary but has been used throughout all computations thus giving a valid comparison between the different values of ballistic coefficients.

Time of fall versus ballistic coefficient for launch altitudes of 40,000, 10,000 and 3,000 feet is plotted in figure 5. The solid lines were constructed from the relation (*) and the broken lines display the variation from (*) predicted by DRIFT. Relation (*) neglects the time required for the store to accelerate from its initial zero vertical velocity to its equilibrium vertical velocity. Program DRIFT accounts for the acceleration time and therefore predicts more accurate but longer times of fall than (*). The time difference increases with increasing terminal velocity, i.e., increasing ballistic coefficient.

Figures 6 and 7 are plots of drift as a function of release altitude with ballistic coefficient as a parameter on rectilinear and log-log scales respectively. Although a slight variation of drift occurs with the speed of the launch vehicle, drifts for launch speeds between 0 and 400 KIAS were averaged to give a unique correspondence between drift and altitude for any value of ballistic coefficient. In the altitude range of increasing wind velocity, i.e. the region under 30,000 feet, the log-log plot was linear indicating for a constant ballistic coefficient drift is an exponential function of altitude. From 30,000 to 40,000 feet the drift-altitude relation is almost linear.

NOMOGRAPH CONSTRUCTION

The time of fall relation (*) may be expressed as

$$t = H(h) B(\beta)$$

where

$$H(h) = 1 - e^{-h/2a}$$

and

$$B(\beta) = a \left(2\rho_0 \frac{C_D S}{W} \right)^{\frac{1}{2}}$$

This relation permits the construction of a zee type nomograph with a linear time scale and the altitude scale proportional to the fraction $H(h)$. The β scale and the terminal velocity scale may then be constructed graphically to best match the output of DRIFT.

Consider the portion of the altitude-drift plot which is linear on a log-log graph, i.e., the portion corresponding to store release altitudes from 0 to 30,000 feet. Altitude, h , and wind drift, D , are related by

$$\ln h = .8 D + \ln h_0(\beta)$$

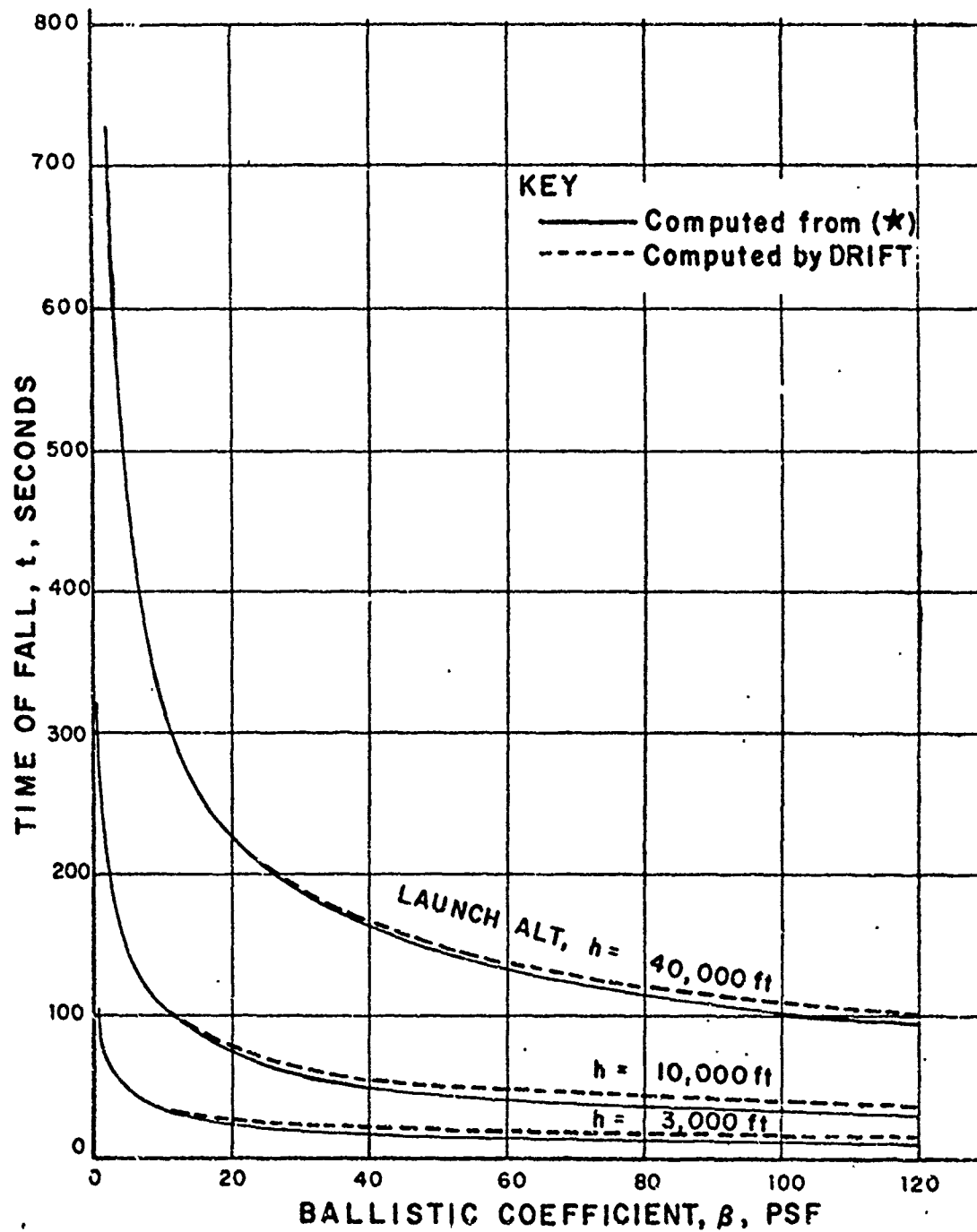


Figure 5. Time of Fall Curve

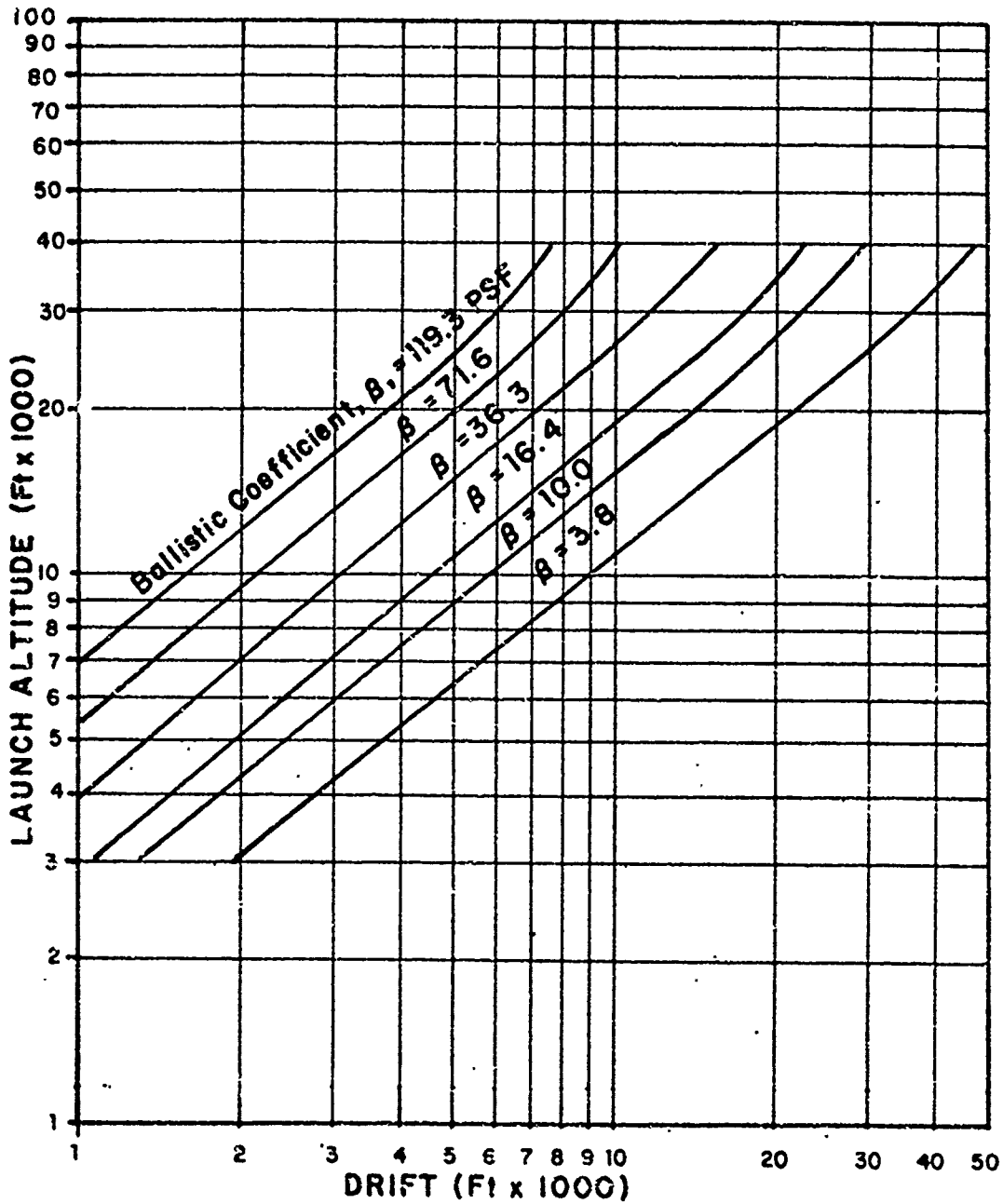


Figure 6. Logarithmic Drift Curve

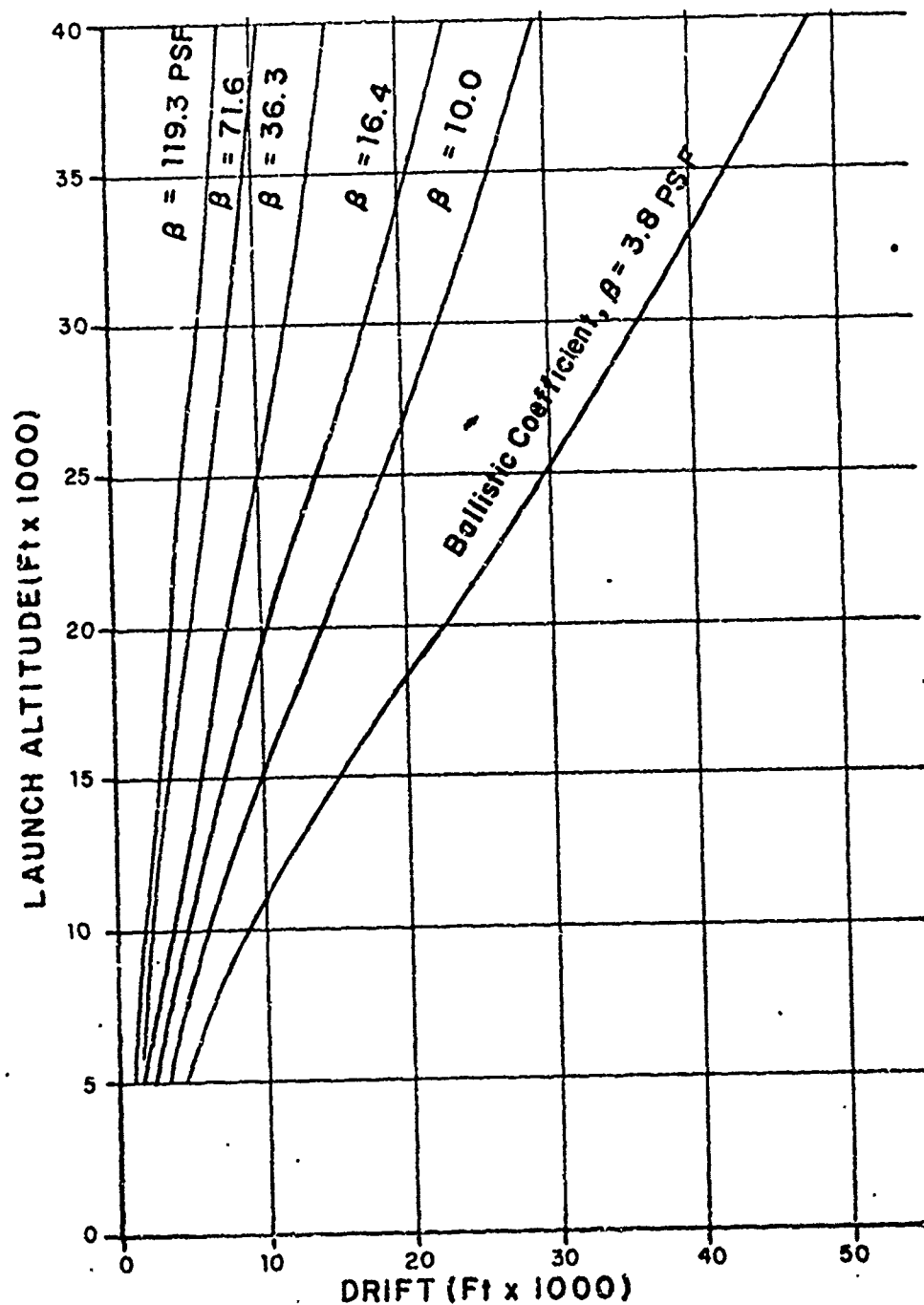


Figure 7. Linear Drift Curve

where h_0 , a function of β , is the h intercept of the altitude-drift plot. This may be rewritten as

$$D = 1.25 \left[\ln h - \ln h_0(\beta) \right]$$

or

$$D = \left[\frac{h}{h_0(\beta)} \right]^{1.25}$$

Defining a new function of β , $D_0(\beta)$, by

$$D_0(\beta) = \left[h_0(\beta) \right]^{-1.25}$$

$$D = D_0(\beta) h^{1.25} \quad (**)$$

Either a zee type or parallel scale nomograph may be constructed. The zee type would have one linear scale, one scale proportional to D or h raised to a constant power and a β scale geometrically constructed. The parallel scale nomograph, however, was chosen to represent (**). D and h were plotted on logarithmic scales and the β scale was geometrically constructed.

Launch altitudes above 30,000 yield a nearly linear altitude-drift relation for any value of β . Beginning with linear h and D scales, iterative construction was used to construct an altitude scale which yielded results consistent with the output of program DRIFT.

The constructed size of figure 1 was 34 x 44 and figures 2 and 3 were constructed at 25 x 33. All three nomographs were then photo-reduced to the 6½ x 8½ format included herein.

ACCURACY

A short evaluation of the nomographs was performed to determine their accuracy. Several points were read over the entire range of both launch altitude and ballistic coefficients by two individuals. These readings were compared to the data from DRIFT and (*) and the results are discussed below.

Data from the time of fall nomograph, figure 1, is always within three seconds of the time given by (*). When the launch altitude is low the line constructed through the data points intersects the terminal velocity - ballistic coefficient axis at a small angle. Thus small errors in construction are amplified and the percentage error may be high; however, the maximum error below 10,000 feet was still only 1.8 seconds. Launch altitudes of 10,000 feet and above result in less than three percent error for the entire range of ballistic coefficients.

The preceding paragraph discussed the error in time of fall when compared to the relation (*). When nomograph times are compared to the times predicted by DRIFT the error may become greater. Times from the nomograph will be less than those from DRIFT for ballistic coefficients greater than ten or twenty pounds per square foot. Figure 5 displays the expected difference which is a maximum of 10 seconds. The percentage error between the nomograph and the time from DRIFT is less than fifteen percent for launch altitudes of 20,000 feet and above and does not exceed ten percent for ballistic coefficients below fifty pounds per square foot from launch altitudes of 10,000 feet and above. Table I shows launch altitudes (as a function of ballistic coefficient) above which the error in using the nomograph will be below ten or fifteen percent.

TABLE I

MINIMUM ACCURATE LAUNCH ALTITUDES
FOR PREDICTING TIME OF FALL

BALLISTIC COEFFICIENT (PSF) TERMINAL VELOCITY (FPS)	10 92	20 130	50 205	75 251	100 290	120 318
MIN ALT FOR 10% T of F ERROR (FT)	3K	3K	10K	20K	40K	40K
MIN ALT FOR 15% T of F ERROR (FT)	3K	3K	10K	10K	20K	20K

The drift nomograph for launches to 30,000 feet, figure 2, has a maximum error of 340 feet and less than seven percent. The maximum percentage errors found were for 5,000 foot launches and corresponded to an error of only 100 feet. At higher launch altitudes the maximum percentage error was less than four percent. The drift nomograph for 30,000 to 40,000 feet, figure 3, has a maximum error of less than three percent.

CONCLUSIONS

Figure 1 provides a rapid, convenient method for solving the relationship between launch altitude, ballistic coefficient (or terminal velocity) and time of fall. Figure 1 also serves to convert between values of ballistic coefficient and terminal velocity. Figures 2 and 3 perform a like function for altitude, ballistic coefficient (or terminal velocity) and wind dispersion.

Figures 2 and 3 yield maximum errors of less than seven and three percent respectively. Figure 1 predicts times which are always within three seconds of the time of fall relation (*). When compared to the results of program DRIFT the error in figure 1 tends to be higher and Table I defines the limitations on its accuracy.

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